MODE HOT LINE NEWS

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A NUMERICAL SIMULATION OF THE MODE-I STATISTICS

by Breck Owens and Francis Bretherton

The MODE-I experiment has given us a glimpse of the statistical structure of a "typical" mid-ocean eddy field. Recent studies (Dantzler, Hot Line News No. 57; Bernstein and White, 1974) support the hypothesis that eddies are generated in the extension of the western boundary current and either advect or propagate through the sub-tropical gyre. There appears to be a factor of about 3 between the eddy energies in the northwest and southeast quadrants, suggesting a decay time comparable to the large-scale circulation time. For a large-scale current of 4 km/day and an e-folding of the eddy energy over 3000 km, this time is 2½ years, which is long compared to the evolution time for individual eddies. This suggests that local non-linear processes may be more important than the precise source and dissipation mechanisms in determining the mid-ocean eddy structure.

In order to understand the local dynamics, a non-linear, six-layered, quasi-geostrophic model developed by Bretherton and Karweit (1975) was used in a 10° square to simulate mesoscale eddies statistically. These were then compared to MODE-I observations. Because MODE-I did not cover a large enough area, the initial conditions and topography used in the model had to be statictically extrapolated, thus precluding a predictive experiment. The stratification and topography were matched to those of the MODE region, leaving only the initial input of potential energy and the bottom Ekman dissipation rate as model parameters. For the proper choice of these parameters, the model energy levels and

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FLOAT TRACKS FOR MAY-DECEMBER, 1974

by Tom Rossby, Diane Dow, and Howard Freeland

Two years have elapsed since the post-MODE float experiment began. At that time, twelve floats were repaired and relaunched. Currently, five or six of these floats are still being tracked (the number depending on whether or not any of the southern floats have moved so close to the West Indies that the islands block their signals). The signals are fading, however, and it may not be possible to track the floats much longer.

Also being tracked is the experimental float No. 4 which was launched at 930 m depth on 21 April 1974 to test signal reception from an off-axis float. Since launch, it has been sinking steadily at a rate of about 1 m/day.

Due to the large dispersal of the floats, the tracks are presented in three different geographical areas. The eastern cluster (Figure 7) shows the experimental float moving rapidly eastward at speeds of about 7 cm/sec. By 1 September 1974, it had sunk to about 1100 m depth, and during the last four months of 1974, it moved around at speeds in the range of 2-3 cm/sec. The other float in this cluster, a post-MODE drift float, was tracked over the rough topography east of the MODE center and has a speed of about 2.5 cm/sec.

The three floats in the northwestern cluster (Figure 8) show some similarity in behavior. All three start out at low speeds in the MODE-I area and eventually head north and west. Their speeds increase substantially as the floats move away from the MODE area.

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A NUMERICAL SIMULATION OF THE MODE-I STATISTICS (continued)

decay times are consistent with observations. Similarly, simulated spatial correlations of dynamic thickness, float and current meter velocity magnitudes and temporal and spatial scales, and vertical structure are in rough agreement with observations within the likely sampling errors. Thus, it appears that the statistical structure of mesoscale eddies is determined locally by non-linear interactions and bathymetry, given the over-all density stratification and an initial input of potential energy.

The model used for these studies covered a 960 km square with a 32 x 32 grid and a depth of 5 km. Periodic boundary conditions were applied to the velocities. The large-scale stratification was chosen to match the first three internal modes observed during MODE-I (McWilliams and Flierl, personal communication). The model radii of deformation, layer depths, and vertical structure of potential density are given in Table 1.

INTERNAL MODE	RADIUS OF DEFORMATION
1	46 km
2	21
3	17

LAYER	THICKNESS	$\delta\sigma$
1	200 m	0.567×10^3 g/cm^3
2	500	0.642
3	500	0.550
4	850	0.182
5	1600	0.110
6	1350	---

Table 1

The linear bottom Ekman dissipation coefficient was about twice that which one would get using a Chézy coefficient for smooth mud and an average bottom velocity of 5 km/day. This dissipation rate is equivalent to a spin-down time for a 5 km deep barotropic ocean of 500 days. For computational stability, a lateral friction, whose decay rate was proportional to the fourth power of the wavenumer, was used to control the vorticity build-up at large wavenumbers. It was significant only in the wavenumber octave 8-16, which is poorly represented by the numerical scheme. The bottom topography is a smoothed version of the MODE region with no variations at wavelengths shorter than 160 km; the Blake-Bahama rise is removed, and the MODE center is shifted to the center of the area of integration. The initial velocities were entirely above the main thermocline and were chosen to have a streamline pattern similar to that inferred from the topography of the 10° isotherm surface observed in MODE-I, extrapolated to fill the area of integration.

The magnitudes in layers 2 (above the main thermocline), 3 (the main thermocline), and 4-6 (below the thermocline-the bottom layer) were respectively .66, .31, and .00 times that in layer 1 (surface layer). This field accounts for the input of energy into the system. Its magnitude was adjusted so that the subsequent r.m.s. speed at level 4 equalled that of the SOFAR floats in MODE-I. Otherwise, the statistical behavior of the model is insensitive to the details of these initial conditions.

The model was run for 200 days to attain quasi-equilibrium. A further integration of 100 or 200 days generated the model statistics. During the latter integration, only the magnitudes of the velocity and energy spectra decreased due to the bottom Ekman dissipation.

Streamfunction fields shown in Figure 1 for four layers demonstrate the baroclinic nature of the flow. There is only slight visual correlation across the thermocline while the spatial structure of the upper layers varies little with depth and that of the bottom layers changes only due to bottom intensification.

A further indication of the baroclinicity of the flow is the shift of the maximum in the one-dimensional velocity spectra to higher wavenumbers as the depth increases (Figure 2a). The one-dimensional spectra presented in this paper were obtained by taking east-west cuts and averaging in the north-south direction.

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A NUMERICAL SIMULATION OF THE MODE-I STATISTICS (continued)

The spectra obtained by averaging in the east-west direction are identical to those averaged in the north-south direction, except for their magnitudes, which are smaller. The spectral shapes do not change above or below the main thermocline, but vary greatly across it. The r.m.s. speeds (Table 2) vary across the thermocline by a factor of 2.

LAYER	R.M.S. SPEED
1	11.8 km/day
2	8.4
4	4.4
6	5.7

Table 2

The simulated structure function of dynamic thickness across the main thermocline is compared in Figure 2b to the MODE-I and historical values given by Dantzler (Hot Line News No. 58). The model is in agreement with a dominant length scale of $\sim$300 km to well within the accuracy of the observational results.

The westward propagation of the eddies is shown by the phase diagrams in Figure 3 (east-west cross sections of the streamfunction field versus time) for layer 4 just below the main thermocline, and for the SOFAR float analysis (Freeland et al, 1975). Figure 3 is a cut through the relatively flat central region. The westward propagation is well organized with an average speed of $\sim$7 km/day (a subjective choice; we are open to any other bids) which agrees well with the SOFAR floats. However, this should not be taken too seriously. If a cut through the southern region of the model where there is a large topographic feature is used, there is an apparent blocking effect causing the propagation to be disorganized.

Figure 4 shows the principal axes of the velocity variances in level 4 averaged over one-degree squares, analogous to a similar plot in Freeland et al, (1975). Qualitatively the plots are similar, but quantitative intercomparisons of the variances are not possible because the model topography is not exactly equivalent to that of the MODE-I region. The spatial variations in Figure 4 cannot be directly related to specific topography features as Freeland et al have done.

After the first 200 days of the integration, 1024 Lagrangian floats were placed uniformly in layer 4 ($\sim$1500 m depth) and "tracked" for 100 days. Taking the floats as representative, averages over the floats and over time gives estimates of the velocity variances, spatial correlation functions, and Lagrangian auto-correlation functions. The velocity variance in the north-south and east-west directions were 6.3 and 92. km^2/day^2, giving a r.m.s. speed of 2.9 km/day.

The Lagrangian auto-correlation functions, Figure 5a, have dominant time scales of 20 and 25 days for the north-south and east-west directions. Integration of the Lagrangian auto-correlation gives the diffusion coefficients (Taylor, 1921) which are 1.2 and 0.6 x $10^6 cm^2/sec$ for the east-west and north-south directions, respectively. This anisotropy is a result of the tendency of parcels of water to move east-west due to the beta effect. These model results are in agreement with MODE-I results, except that the observed velocity variances are greater in the north-south direction than in the east-west direction. This difference may be due to the Blake-Bahama rise, excluded in the model, which would inhibit east-west flow. The transverse spatial correlation function, Figure 5b, had a zero crossing of 75 km, which is longer than that observed by the SOFAR floats, 55 km.

A series of simulated current meter records, Figure 6, looks qualitatively similar to the observations (for example, Schmitz and Payne, Hot Line News No. 48). These records show a ratio of velocities across the thermocline of $\sim$2. There is also a shift to shorter time scales as one goes through the thermocline. A comparison of the time spectra is in progress.

Sixteen current meter "strings" equally spaced over the area of integration were used to calculate the empirical orthogonal vertical modes (Davis, 1975). The first two modes contained over 95 percent of the total variances and were similar to the first two dynamical models computed by McWilliams and Flierl

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(1975). The only discrepancy was in the distribution of energy between these two modes. In the model, the barotropic mode represented 75 percent of the total, whereas in the dynamical modes, it represented only 30 percent. Thus, it appears that the model is too barotropic.

The eddy e-folding time (total energy/ rate of change of total energy) was 350 days. This is shorter than one would expect from the Gulf Stream generation hypothesis.

We believe that this comparison of the model with the MODE-I field results has demonstrated that we can statistically simulate the dynamics of mesoscale eddies away from their source. Agreement with the statistics obtained from MODE-I is better than we initially expected. The only deficiencies of the simulation are that the model is more barotropic than indicated by the observations and that the eddy decay time may be too short.

References

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FLOAT TRACKS FOR MAY-DECEMBER, 1974 (continued)

One float breaks away to the north at speeds of up to 8 cm/sec. (Note that this is the first float in the experiment to pass north of 30°N.) The other two floats approach within about 4 km of each other and gain cyclonic (!) curvature as they move into shallow water on the outer edge of the Blake-Bahama rise.

Because signals were blocked from the listening stations occasionaly, the float tracks in the southwestern cluster (Figure 9) are interrupted. One float that had escaped southward previously from the MODE-I area was lost for about one month in June and July, 1974. It returned, however, into the tracking area and eventually became the only float to return to the MODE area from the south. It then escaped southward once again.

A composite view of all the float tracks is shown in the "spaghetti" plot in Figure 10. This plot includes all of the SOFAR float trajectories from November, 1972 through December, 1974. The experimental float No. 4 is not included in the plot, nor are the floats launched in Richardson's Gulf Stream ring experiment. The trajectory around 22°N, 69°30'W is difficult to interpret. This float, No. 20, moved slowly and erratically northeast of Puerto Rico. Its proximity to the islands frequently shadows it from the listening stations. A rough measure of typical speeds is indicated by the spacing of fixes along trajectories (at one-day intervals). Generally, kinetic energy levels increase to the north, south, and west of the central MODE area, and decrease to the east. The character of the float tracks also seems to change in the different geographical regions. Where the speeds are low, the float tracks are more erratic; at large wavenumbers, the tracks exhibit some structure.

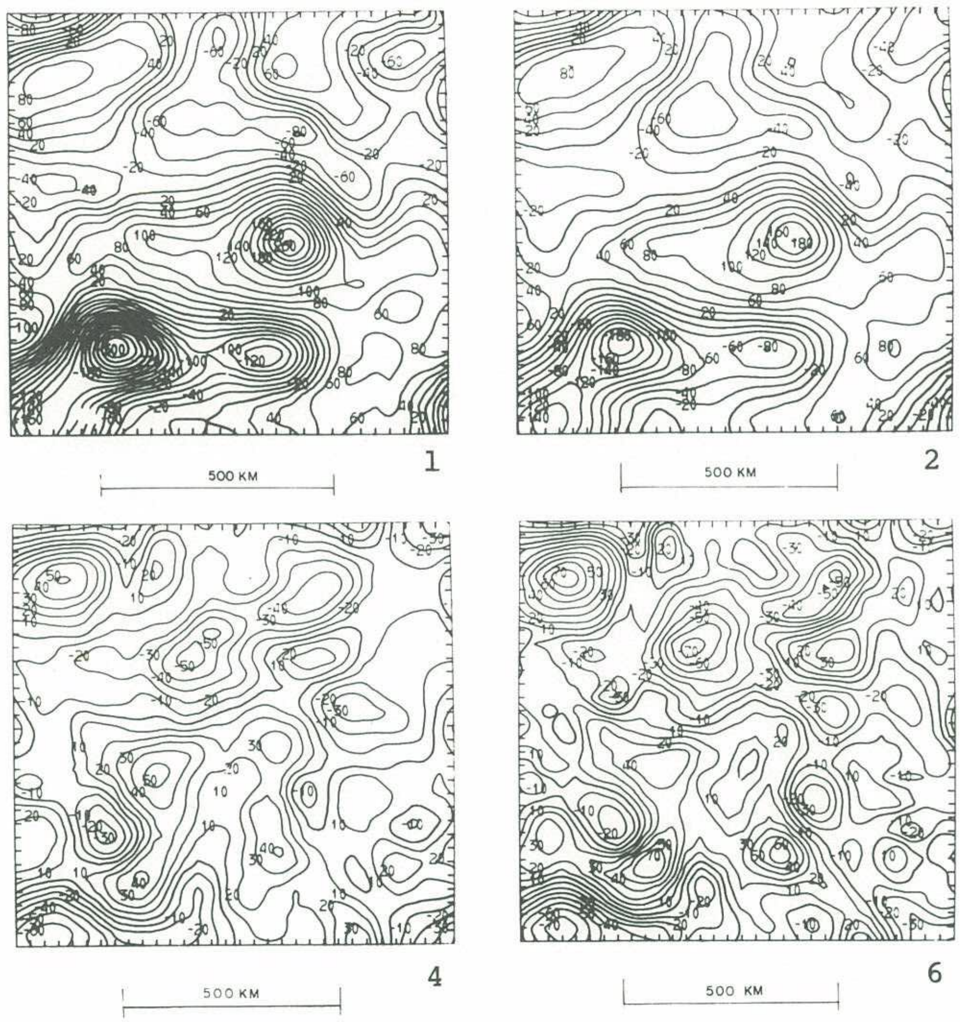
Dynamics and the Analysis of MODE-I

The final report of the MODE-I Dynamics Group entitled Dynamics and the Analysis of MODE-I is being distributed. If you have not received a copy by late July and would like to have one, please contact Ms. Polly Wilbert, POLYMODE Office, Room 54-1417, Massachusetts Institute of Technology, Cambridge MA 02139, Telephone (617) 253-7828.

ERRATUM

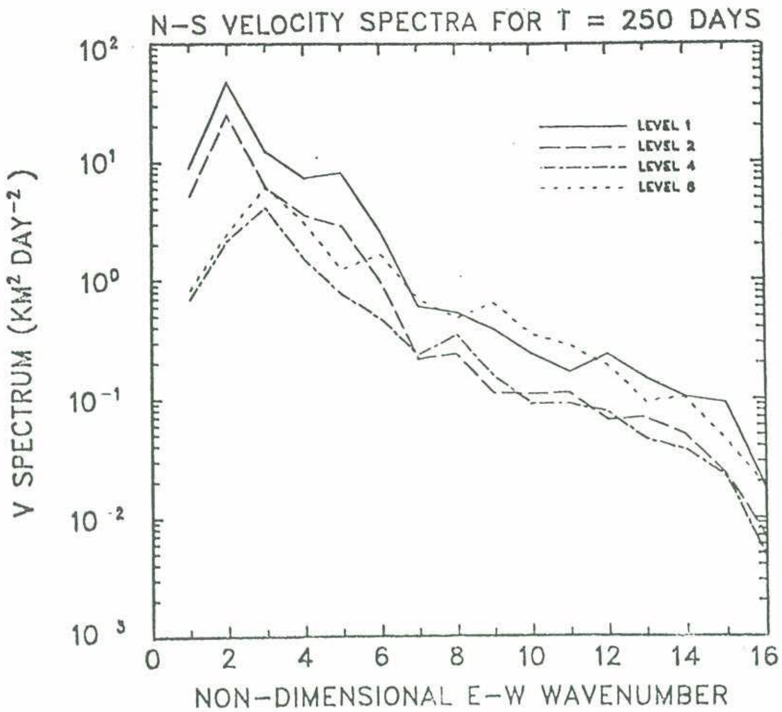
ROSSBY-WAVE SIMULATION OF SOFAR FLOAT TRACKS
by Joyce Tranter and David Webb
(Hot Line News No. 75)

Figure 3 is the simulated float track at 800 m with streamlines superimposed, not at 1500 m.



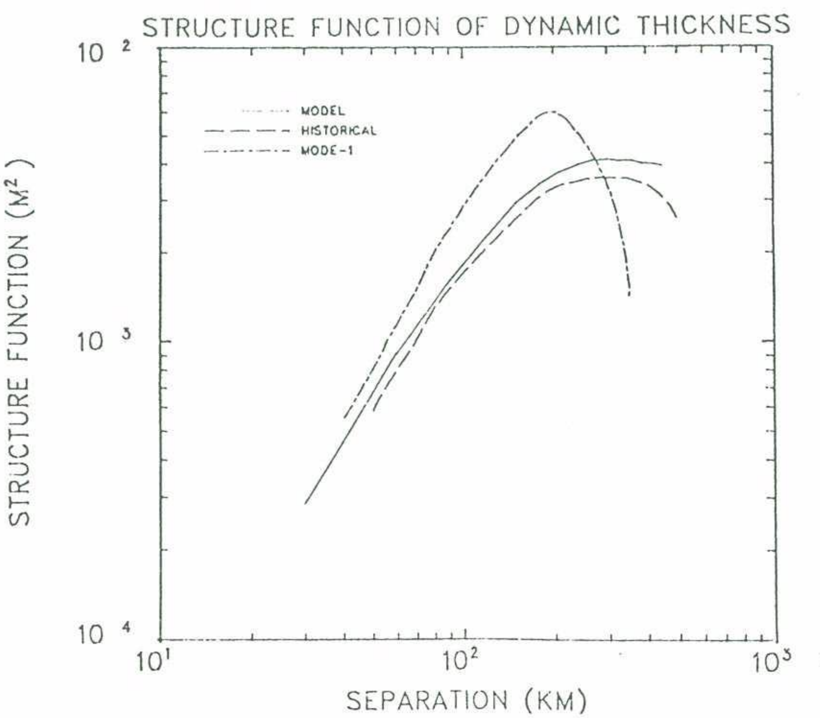
Streamfunction fields for layers 1 (surface layer), 2 (above the main thermocline), 4 (below the thermocline), and 6 (bottom layer) demonstrating the baroclinic nature of the flow. (Note change in contour interval for layers 4 and 6.)

Figure 1 (Owens and Bretherton)



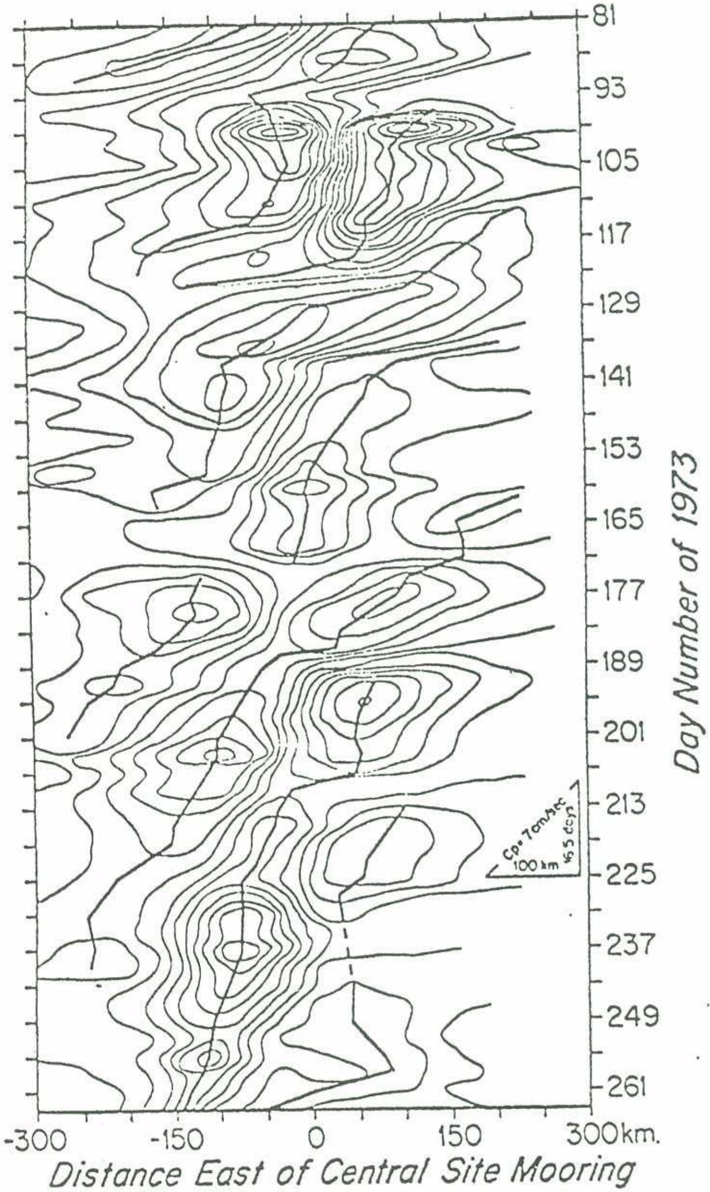
Simulated one-dimensional velocity spectra. Note shift to higher wavenumbers as depth increases, indicating baroclinicity.

Figure 2a

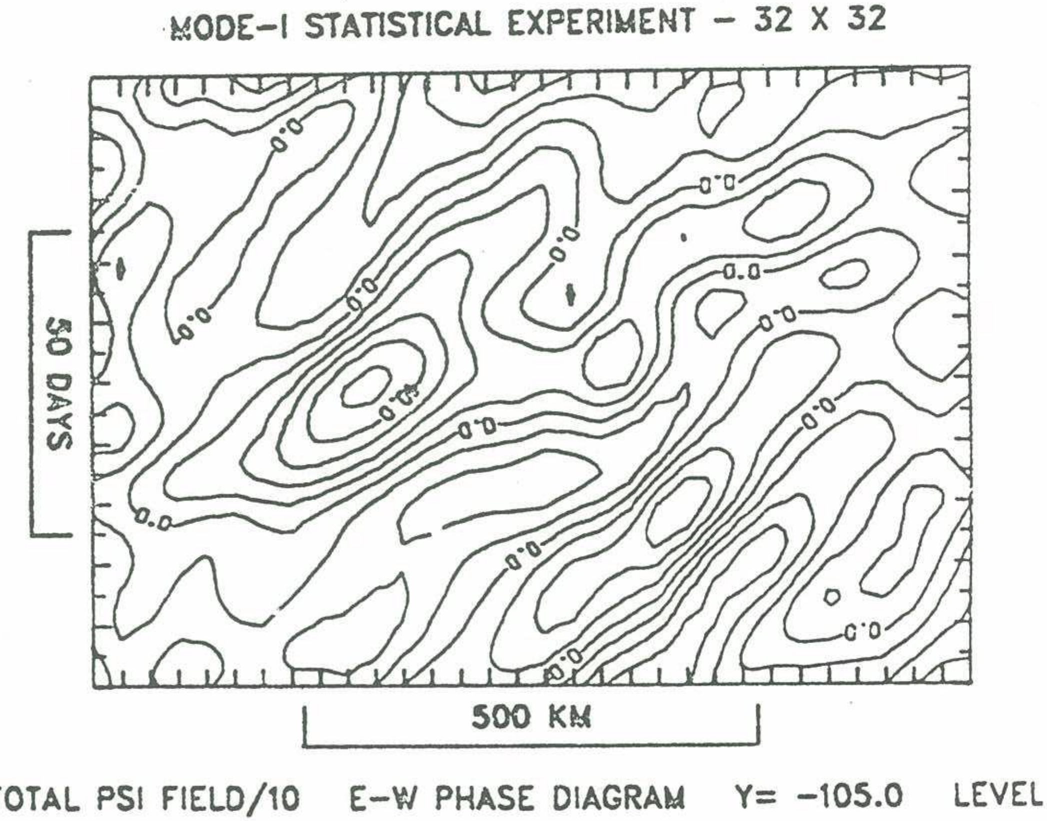


Simulated structure function of dynamic thickness across the main thermocline.

Figure 2b
(Owens and Bretherton)



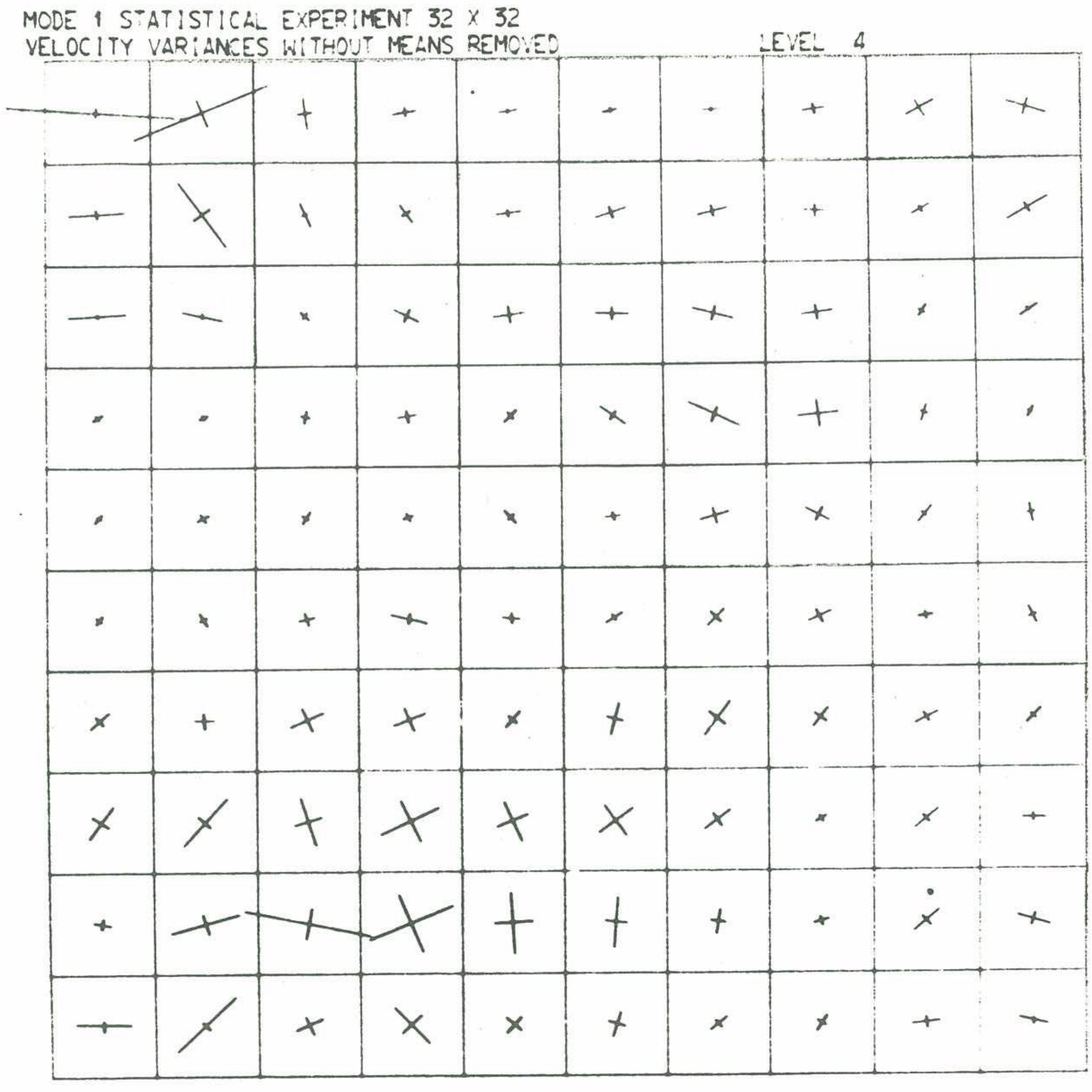
(a)



(b)

Phase diagrams (east-west cross-sections of the streamfunction field vs. time) for (a) the MODE-I SOFAR float analysis and for (b) layer 4 (below the main thermocline). (This is a cut through th relatively flat central region.)

Figure 3 (Owens and Bretherton)



The principal axes of the velocity variances
in level 4 averaged over one-degree squares.

Figure 4 (Owens and Bretherton)

LAGRANGIAN AUTOCORRELATIONS FOR LEVEL 4

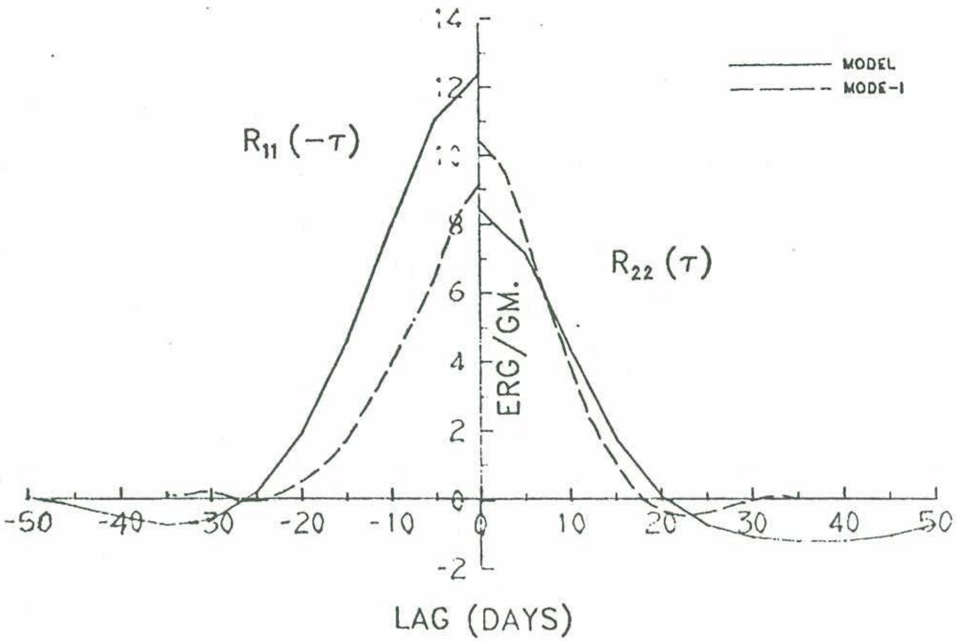


Figure 5a

SPATIAL CORRELATION FUNCTIONS FOR LEVEL 4

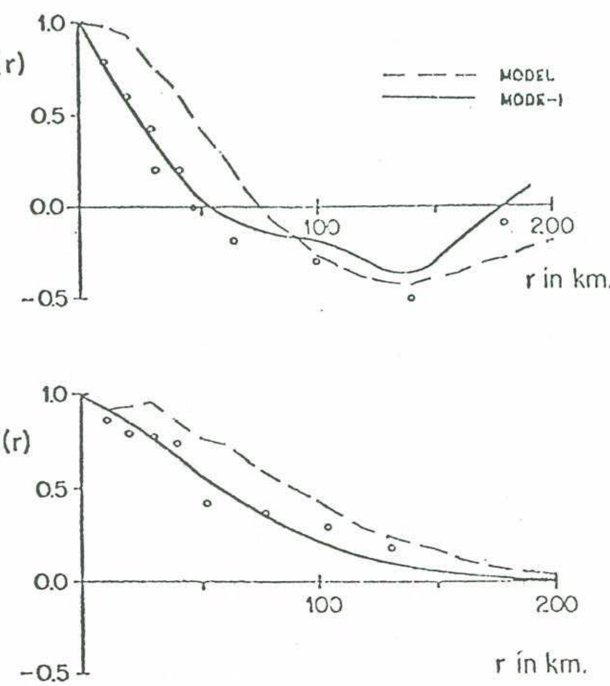
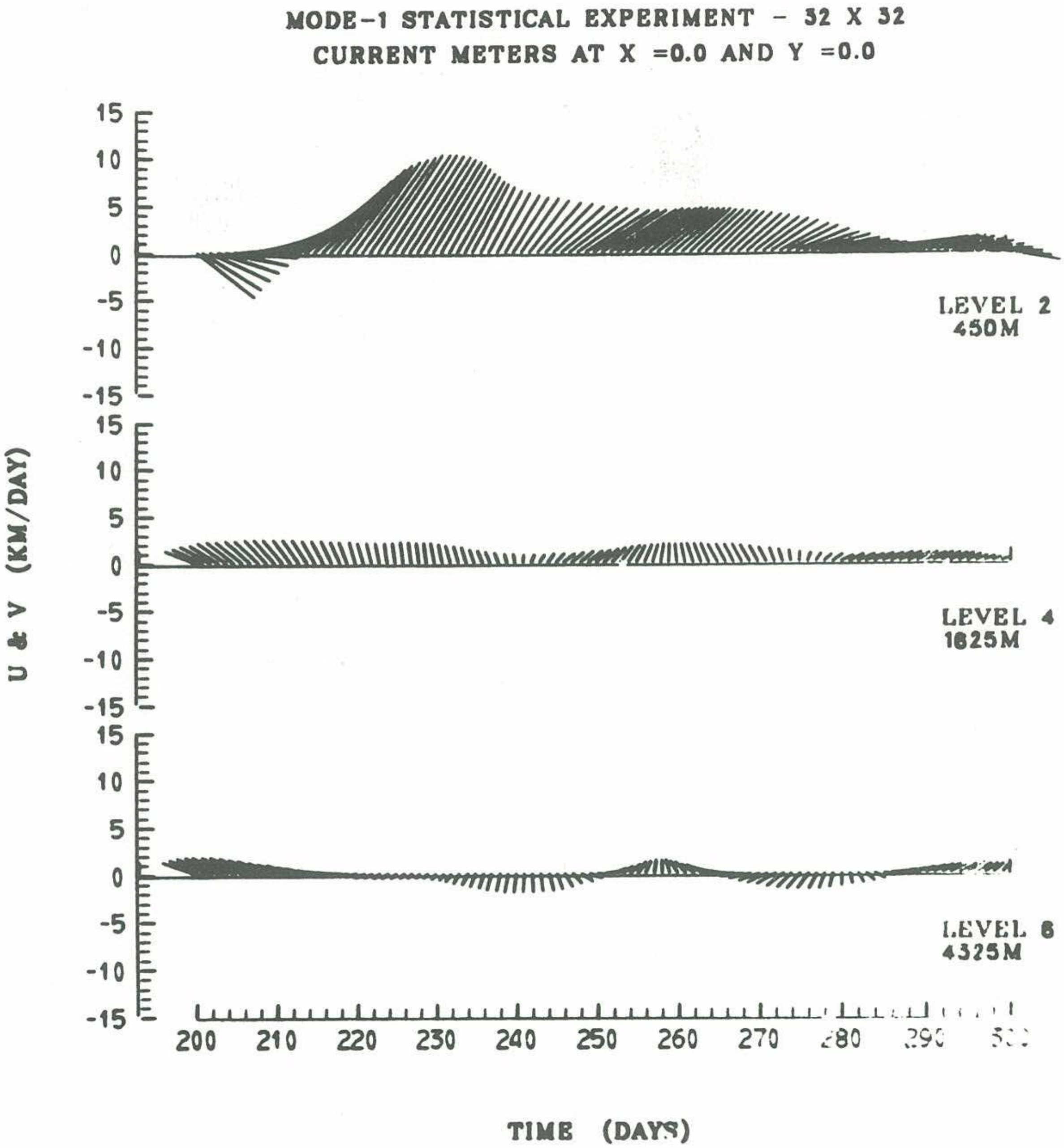


Figure 5b
(Owens and Bretherton)



Simulated current meter records. The ratio of velocities across the thermocline is about a factor of 2.

Figure 6 (Owens and Bretherton)

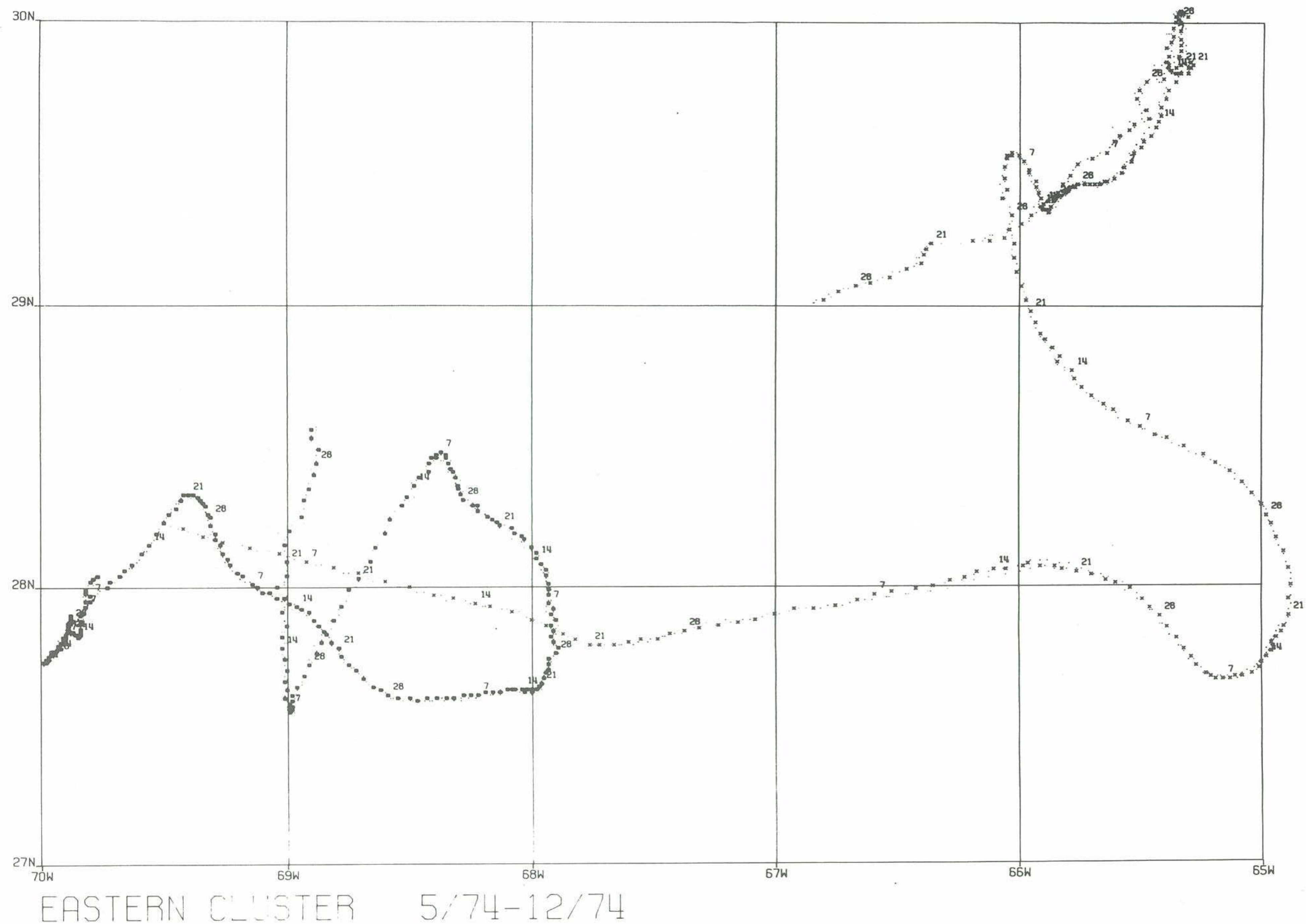


Figure 7 (Rossby et al)

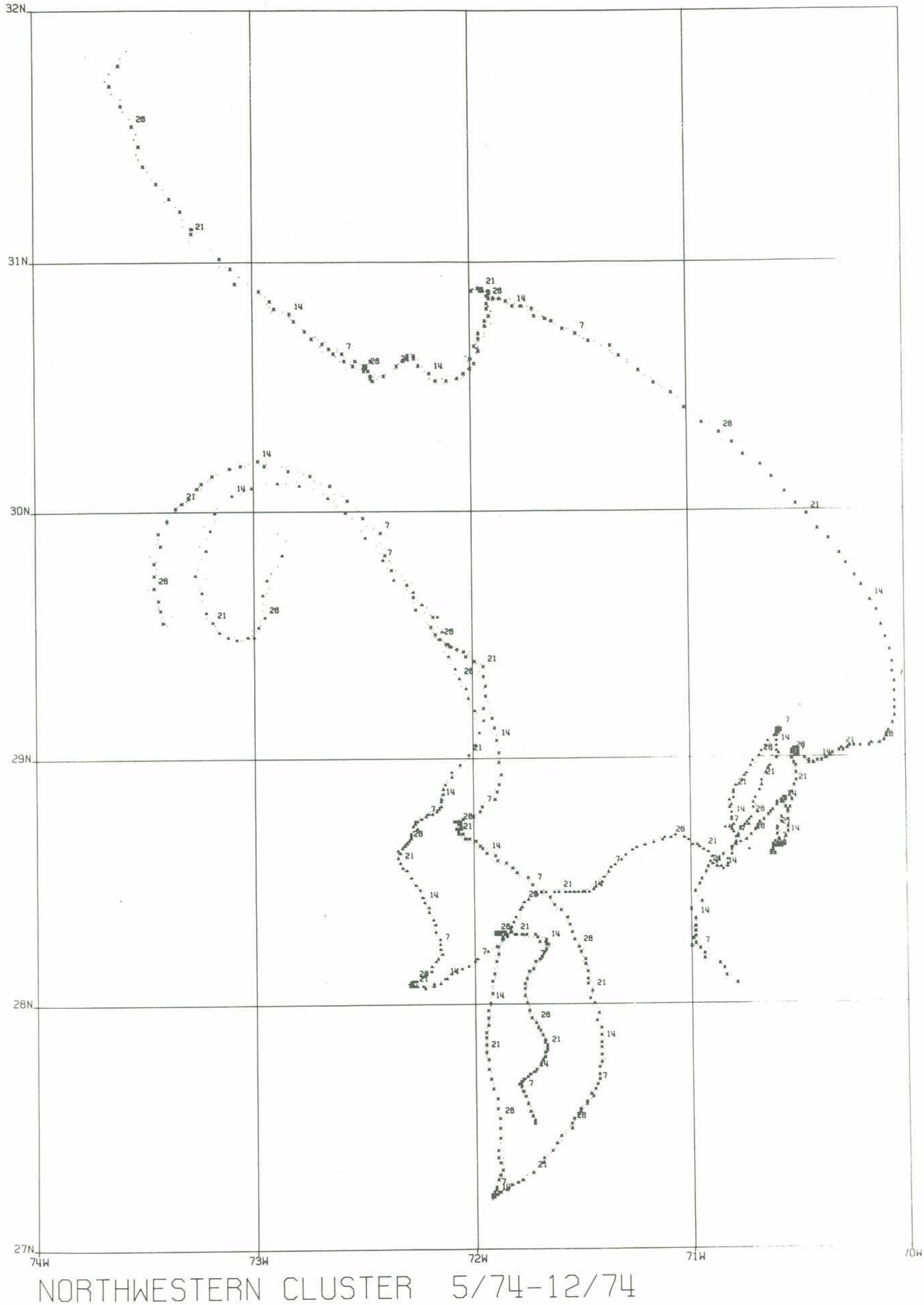
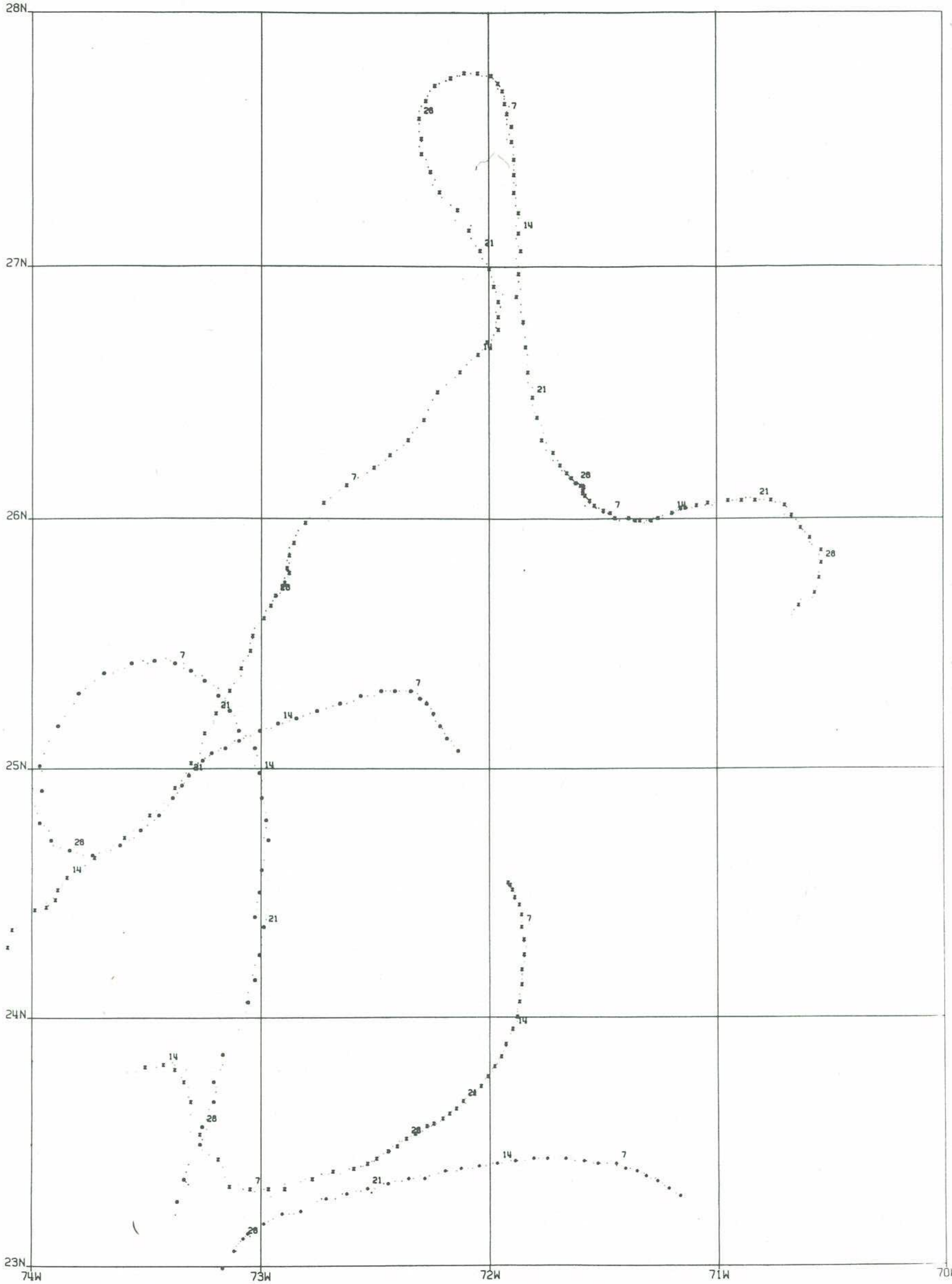


Figure 8 (Rossby et al)



SOUTHWESTERN CLUSTER 5/74-12/74

Figure 9 (Rossby et al)

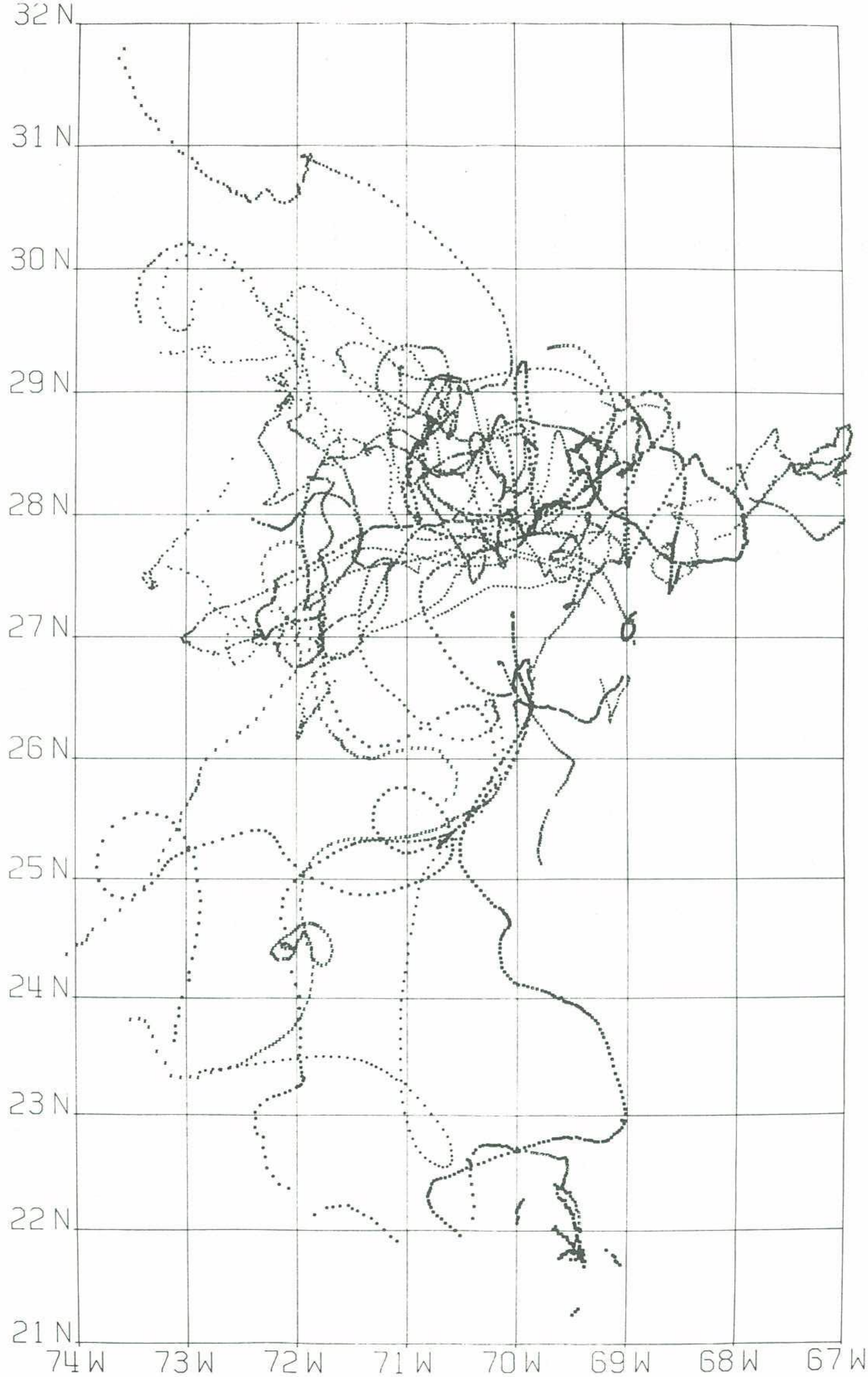


Figure 10 (Rossby et al)

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If you have material of interest for this newsletter, please get in touch with either of the above at the Woods Hole Oceanographic Institution, Woods Hole MA, 02543, Telephone (617) 548-1400.

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